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Calibration of a Spark-Gap for Measurement of High Potentials

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CALIBRATION OF A SPARK-GAP
FOR
MEASUREMENT OF HIGH POTENTIALS

BY

HARRY GARDNER WOOD

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

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June 1, 1914

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Harry Gardner Wood

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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Calibration of a Spark Gap
for
Measurement of High Potentials.

Introduction

Within the past two decades the use of high potential transmission has grown much faster than the means of accurately measuring these voltages. True, especially constructed apparatus has been devised for the purpose, but the greater part of this is suitable for labratory work only. It has been found that the breakdown voltages across certain forms of spark gap has sufficient consistency to be used as a voltmeter. Altho up to the present writing the dielectric strength of air is not perfectly known and results obtained by different experimentors under different circumstances differ slightly, yet the results obtained by reasonably careful work give curves the dimensions of which fall within the range of allowable experimental error.

The purpose of this thesis is to determine some of the conditions effecting the accuracy of voltage determinations by means of a spark gap, and to find, if possible, whether or not a gap other than the recognized needle and sphere gaps would give consistent results. The tests of sphere gaps were made with a series of spheres ranging in size from two inches to ten inches, with increments of two inches. The other gap tested consisted of a plain surface and a sphere, the plain surface having an area large compared with the sphere.

Description of Apparatus.

For the majority of these tests, the high potentials were obtained from a special testing transfromer manufactured by the General Electric Company. A cut of this apparatus will be found on the following page (Fig 1). The rating of the transformer is as follows.

Capacity: 100 K W at 60 cycles

Voltage: 125/150,000-100,000-200,000 volts.

Currents: 50-.5 amperes (secondary)

Ratio of Windings: 400-800-1600 /1

The control of the voltages was maintained by means of two switch boards, the connections of which are shown on the second page following. (Fig 11).

The remainder of the tests were run upon a transformer built by the Electrical Engineering Department of the University of Illinois. The original winding data no longer holds, but the following approximate rating gives some idea of its capacity.

Capacity: 10 K W at 60 cycles.

Voltage: 100,000 (secondary)

Current: 25 amperes.

Ratio of transformation: About 188.

To limit the short circut current, resistances were included in the circut. In the case of the 100,000 volt transformer, two glass tubes filled with water having a total resistance of .5 megohm were used. For the larger transformer, a number of standard resistance rods were connected in series, sufficient in number to keep the current within proper bounds.

To keep high frequency oscillations from traveling back from the gap into the transformer, choke coils were inserted in

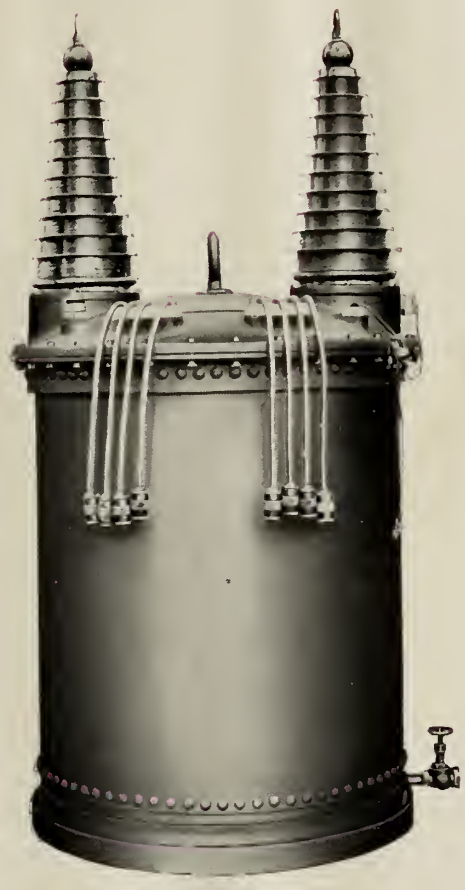


FIGURE 1

A 200,000 VOLT TRANSFORMER

Courtesy The General Electric Co.

Fig. 1.

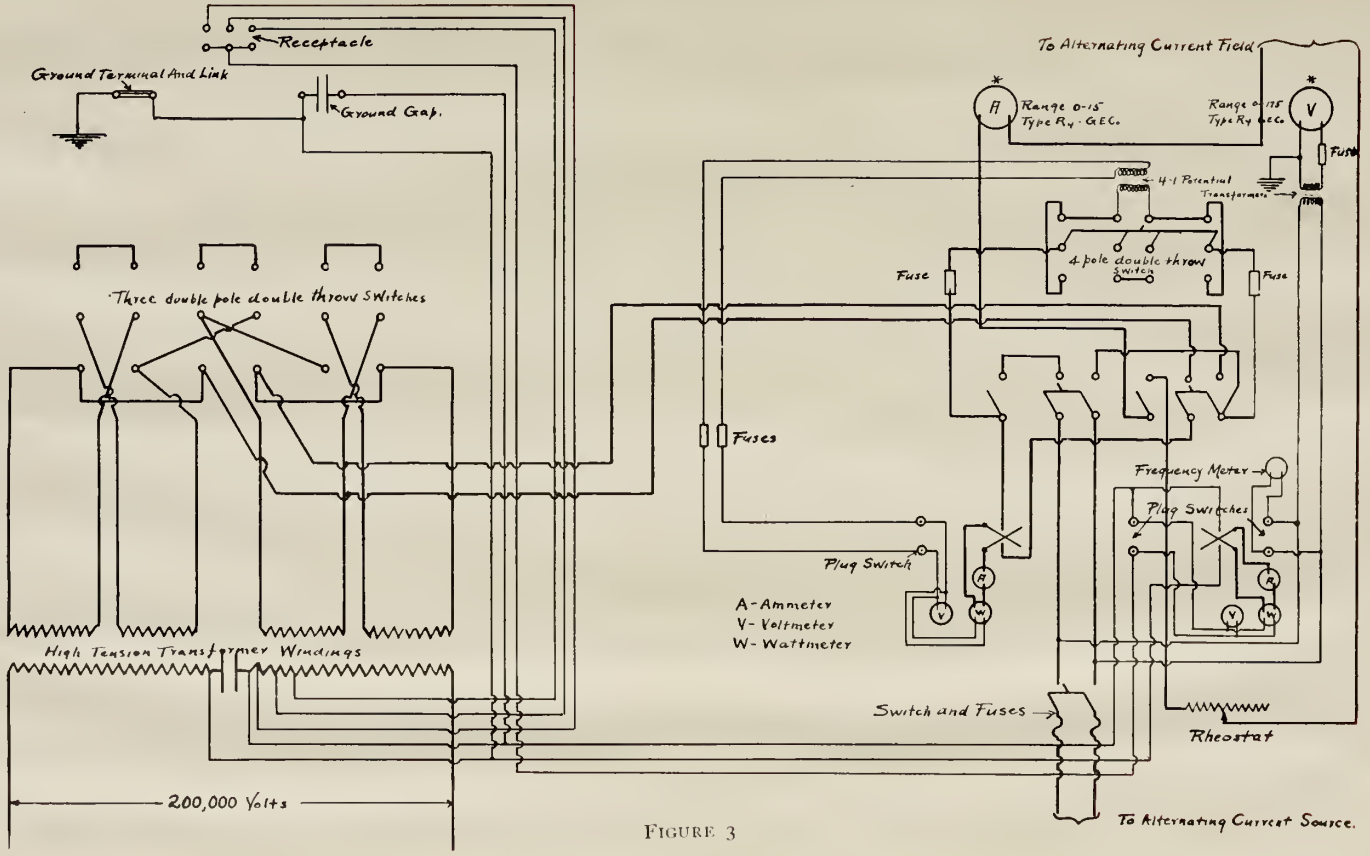


FIGURE 3

SWITCHBOARD WIRING (Back View)

All Meters Not Marked With * Are Enclosed in Drawers

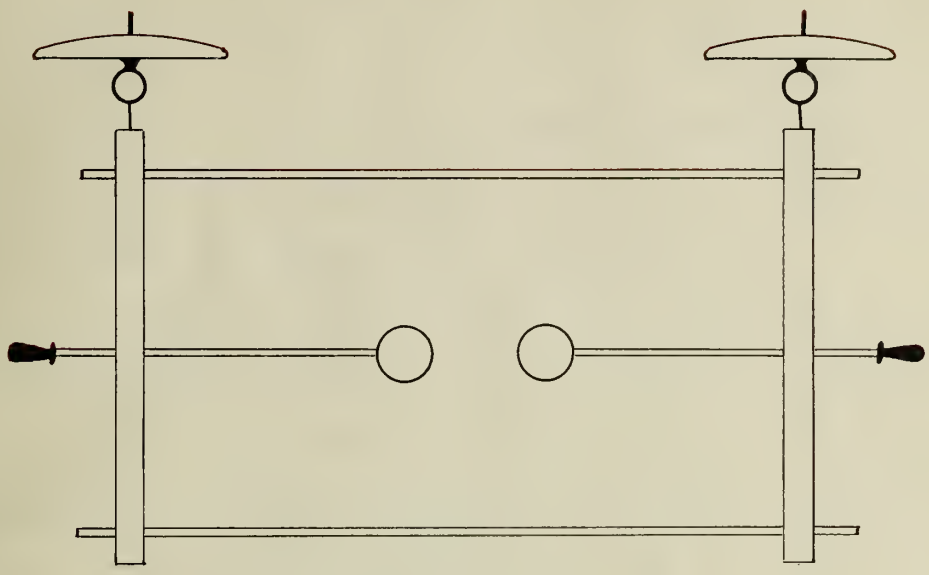
Fig. II.

series with the gap.

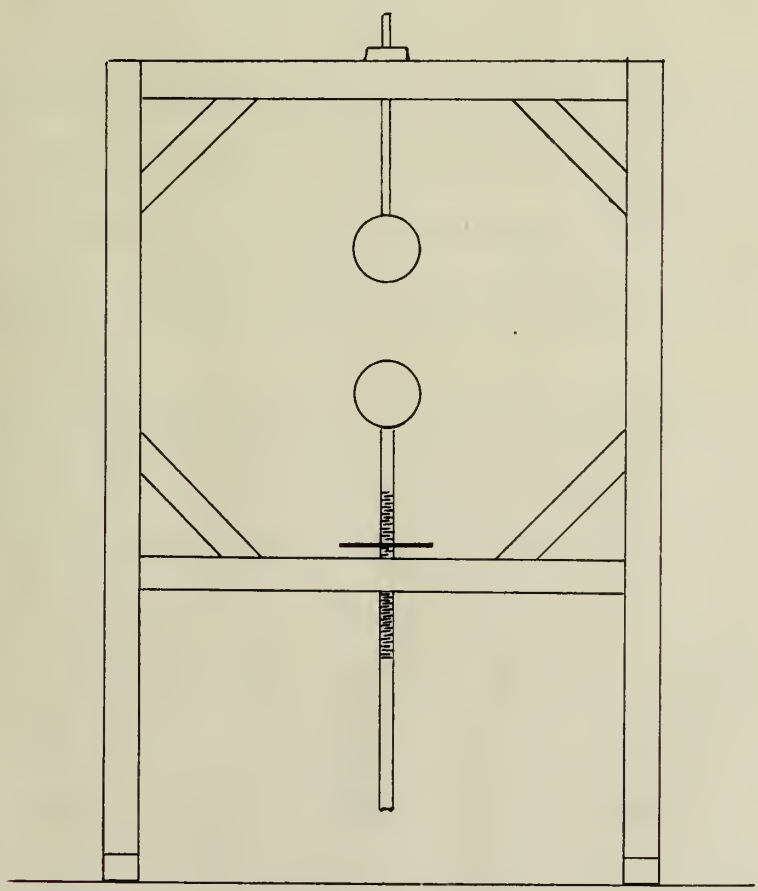
Tests were conducted upon two spark gaps. On the smaller transformer, the horizontal gap constructed by E.R.Coolidge and C.W.Gates in 1913 was used. It consisted of two wooded strips, suspended from strings of high tension disc insulators. The wooden strips were held parallel and rigid by the two glass rods. Midway between the glass rods two brass rods 3/8" in diameter sliding in metal bearings were placed. The ends of these rods were threaded to hold the spheres used in the tests. The length of the gap was measured by means of a pair of calipers.

The spark gap used on the G.E.Transformer was patterned after the Westinghouse Standard sphere gap. The accompanying sketch makes its workings plain. The spheres are placed one above the other so that the gap is vertical instead of horizontal. The upper sphere is held in position by a steel rod which is secured by a set screw in a collar. The spindle for the lower sphere is threaded and contains a graduated dial so that vertical distances could be measured with great accuracy. (Fig 1V).

The primary voltages were obtained from two machines. The G.E. transformer was excited by one phase of a Westinghouse two phase, 440 volt, 45 K W,60 cycle alternator belted to a Westinghouse 60 horse power, 220 volt direct current motor. The other transformer received its power from a smooth core alternator built by the Thomson Houston Company. The last named machine is rated at 1100 volts at 1500 R P M, 125 cycles, and is belted connected to a 25 H.P Edison bipolar motor.



Horizontal Spark-Gap
Fig. III.



Vertical Spark-Gap.

Fig. IV.

Procedure.

When transformers are used to obtain high potentials, there are three or four doffernet ways of measuring the voltage. The simplest, and best known, is by measuring the primary voltage and multiplying by the ratio of turns in secondary and primary windings. This method gives results which are fairly accurate, altho no account is taken of the impedance drop.

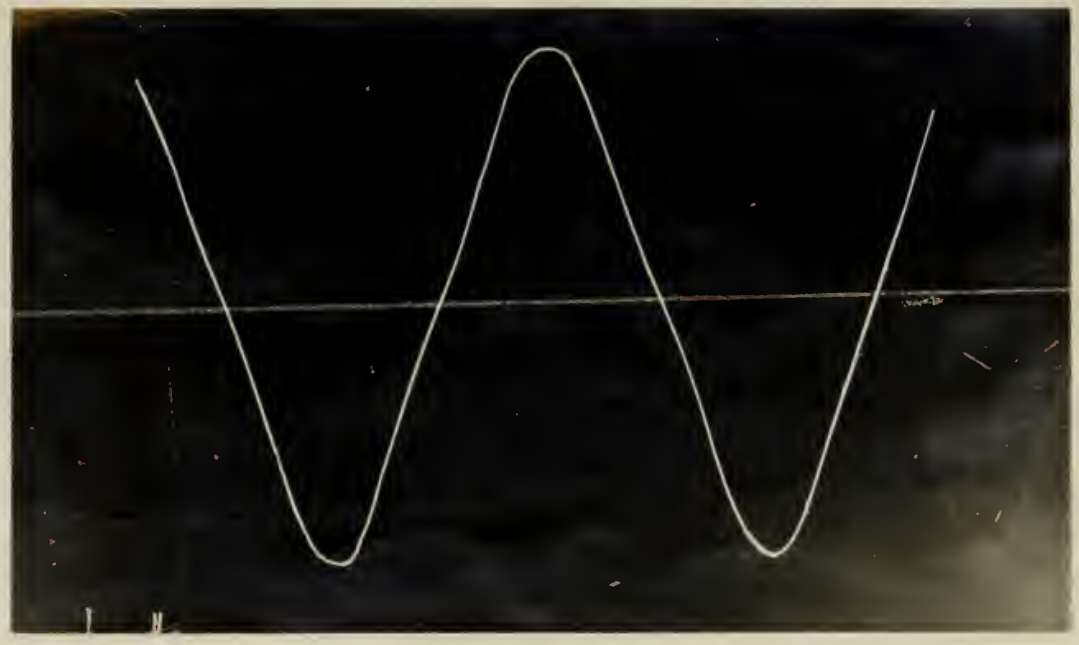
A second method, more accurate than this, is to use a potential transformer, in which the ratio of transformation is used to read the high voltage from the lower. This method gives good results if a properly designed potential transformer is used, but it is open to the criticism that a second, usually expensive, transformer is needed and the apparatus is not readily portable.

A third method was employed by Chubb and Fortescue. They employed a condenser and a galvanometer to read the voltage. This method is more fitted for laroratory testing, giving very accurate results, but too elaborate to be used in many circumstances.

The method used in this test is only possible with a testing transformer of the type used. A tap is brought out from the centre of the secondary. Three other taps are connected so that, connected to the first one, there is a certain definite proportion of the secondary voltage across the terminals. In the transformer used, these taps had the values of $\frac{1}{500}$, $\frac{1}{1000}$, and $\frac{1}{2000}$ of the secondary voltage. At the same time, these values were checked by taking the impressed voltage and multiplying by the ratio of transformation.

The wave form of the 45 K W set is very nearly a sine wave, a slight tripple being almost the only harmonic. The wave form after passing thru the transformer is slightly altered, but even this wave has the relation of .672 to 1.00 (effective to maximum) instead of .707 to 1.00 for a true sine wave.(Fig V). The smooth core machine gave almost a pure sine wave, but no oscillograph record of the wave after passing thru the transformer was available. As the transformer is rather poorly designed, however, a comparitively large distortion would be expected.

Voltage control was obtained by regulating the field of the alternator. The spark gap was set the desired distance, and the voltage brought up as slowly as possible until breakdown occured. Each reading is a mean of at least three trials, although the results of the separate trials aggreed very closely--- there being not more than one half of one percent variation from the mean in most cases.



Characteristic Voltage Wave

Fig. V.

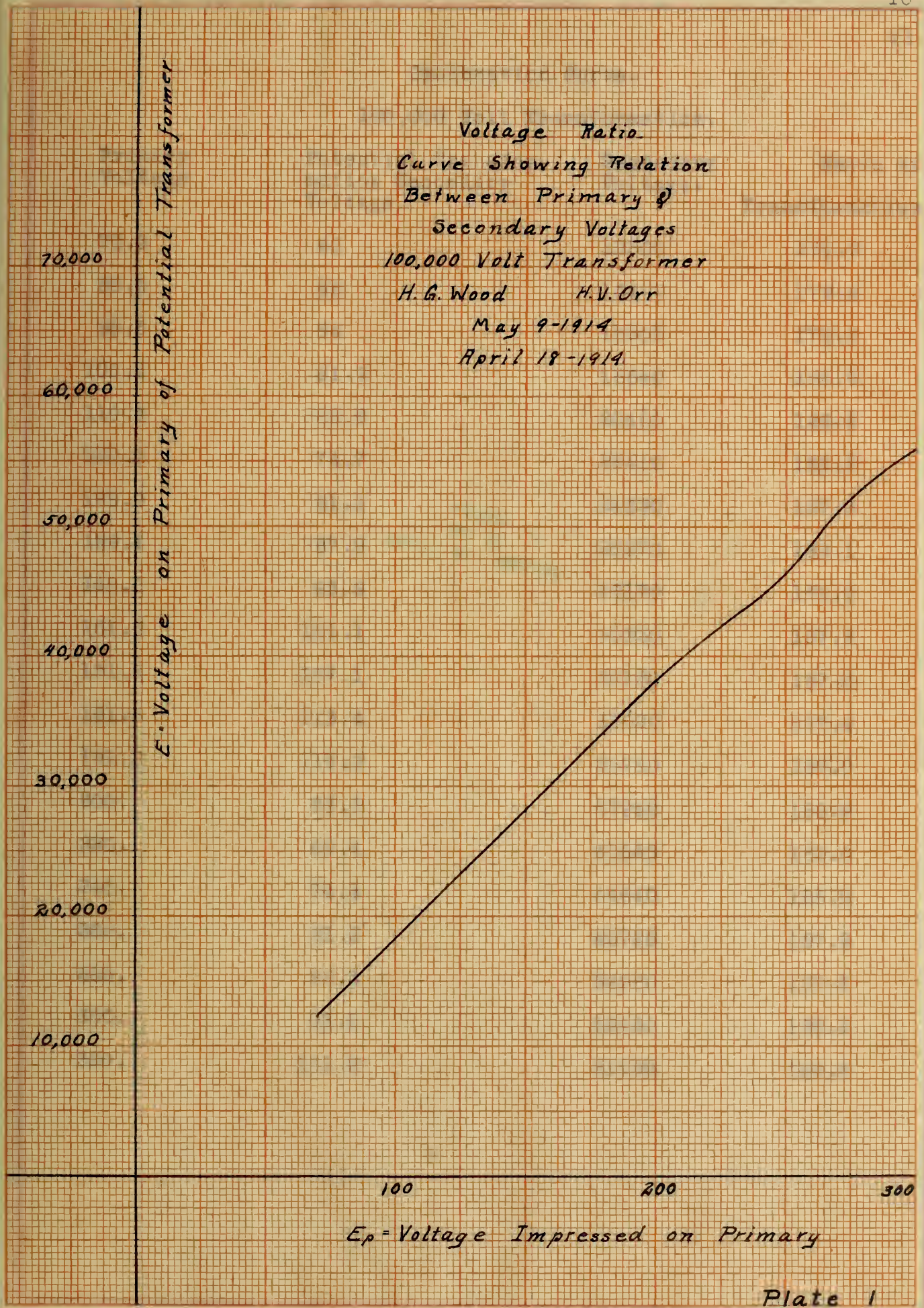


Plate I

NO 346
EUGENE DIETZGEN CO. CHICAGO NEW YORK

Plate 1

Voltage Ratio
Curve Showing Relation
Between Primary &
Secondary Voltages
100,000 Volt Transformer
H. E. Moore Eng Corp
May 9-1914
Serial 79-1914

E - Volts on Secondary (Transformer)

E_p - Voltage Impressed on Primary

10,000
20,000
30,000
40,000
50,000
60,000
70,000

100
200
300

Calibration Curve.

100,000 Volt Transformation.

Primary Voltage	Potential Transformation Secondary Voltage.	Secondary Voltage.	Ratio of Transformation
70.3	41	12300	174.9
80.5	48	14400	178.8
90.5	54	16200	179.0
100.4	61.8	18540	184.6
110.4	68.2	20460	185.3
120.3	74.7	22410	186.2
129.9	81.1	24330	187.3
139.4	87.9	26370	189.1
149.0	93.9	28170	189.0
161.5	101.1	30330	187.8
171.5	107.1	32180	187.6
181.5	113.4	34020	187.4
191.2	119.2	35760	187.0
200.	63.3	37980	189.9
220.	69.4	41640	189.0
240.	74.4	44640	185.9
260.	81.2	48720	187.2
280.	88.3	52980	189.2
300.	93.2	55920	186.2
320.	101.8	61080	190.8

2 Inch Spheres
Curve Showing
Points of Breakdown
H.G. Wood H.V. Orr
May 9-1914.

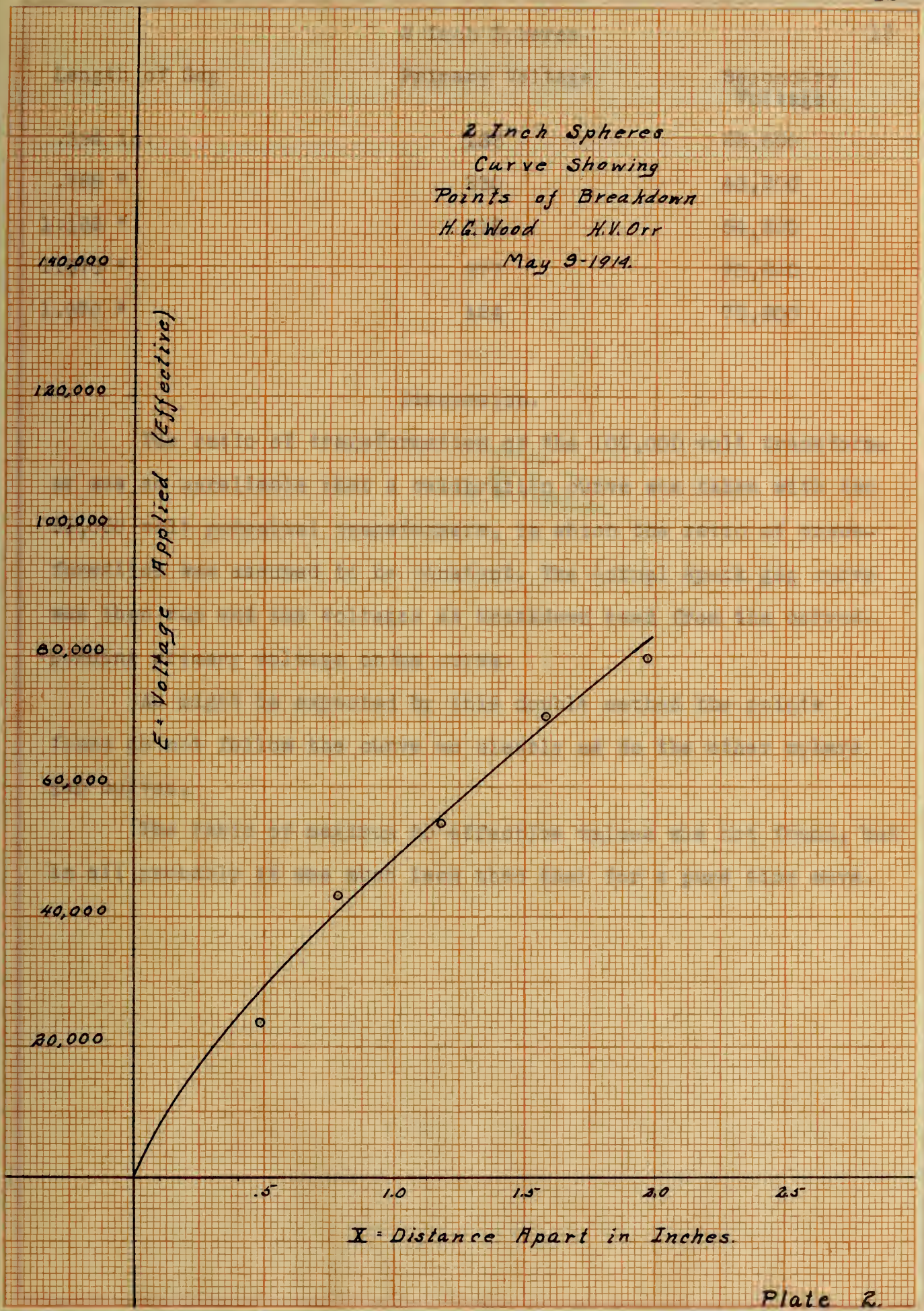


Plate 2.

NO 348
EUGENE DIETZGEN CO. CHICAGO NEW YORK

Plate K

2 Inch Spheres
Curve Showing
Points of Breakdown
R.E. Hoag M.N.Orr
May 3-1914

2 Inch Spheres.

Length of Gap	Primary Voltage	Secondary Voltage.
.394 in.	128	23,600
.788 "	230	43,200
1.182 "	312	54,200
1.576 "	377	70,900
1.970 "	424	79,800

Discussion.

The ratio of transformation of the 100,000 volt transformer was so unreliable that a calibration curve was taken with two 33,000 volt potential transformers, in which the ratio of transformation was assumed to be constant. The actual spark gap curve was then run and the voltages at breakdown read from the corresponding primary voltage onthe curve.

As might be expected by this double method the points found do not follow the curve as clearly as do the other sphere gap curves.

The ratio of maximum to effective values was not found, but in all probably it was much less than that for a pure sine wave.

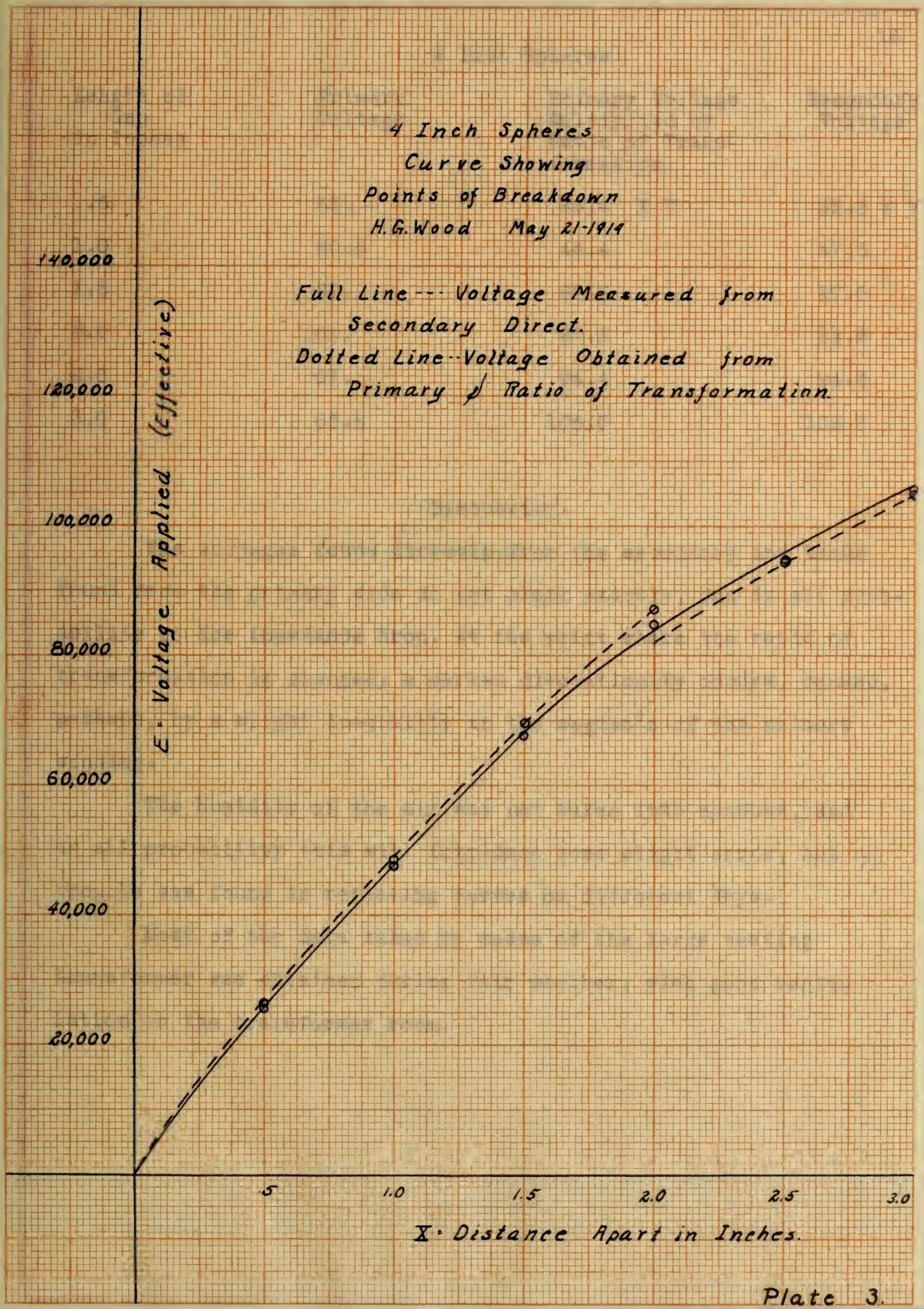


Plate 3.

NO 345

Plate 3

X - Distance Spark in Inches.

E - Voltage (Effective) Radial

Primary & Ratio of Transformation

Dotted line -- Voltage Obtained from Secondary Direct.

Full line -- Voltage Measured from

H.E.Wood May 21-1914

Curve Showing

Points of Breakdown

4 Inch Spheres

4 Inch Spheres.

Lehgth of Gap in Inches	Primary Voltage	Primary Voltage Multiplied by Ratio of Transformation.	Secondary Voltage
.5	33.	26.4 K V	25.5 K V
1.0	60.5	48.4	47.5
1.5	87.	69.6	67.5
2.0	109.	87.2	84.8
2.5	57.	94.4	94.8
3.0	65.6	105.0	105.7

Discussion.

The voltages found directly from the secondary and those found from the primary side do not check exactly, due in all probability to the impedance drop. At the point where the ratio of transformation is changed, a marked discontinuity occurs, caused, perhaps, by a slight inequality in the segments of the primary winding.

The humidity of the air was not taken into account, and in all probability this will introduce some slight error, but no trouble was found in repeating curves on different days.

Most of the data taken by means of the large testing transformer was obtained during fair weather, with good ventilation in the transformer room.

6 Inch Spheres.
Curve Showing
Points of Breakdown.
H.G. Wood May 21-1914

Full Line ---- Voltage Measured from Secondary Direct.
Dotted Line -- Voltage Obtained from Primary & Ratio of Transformation

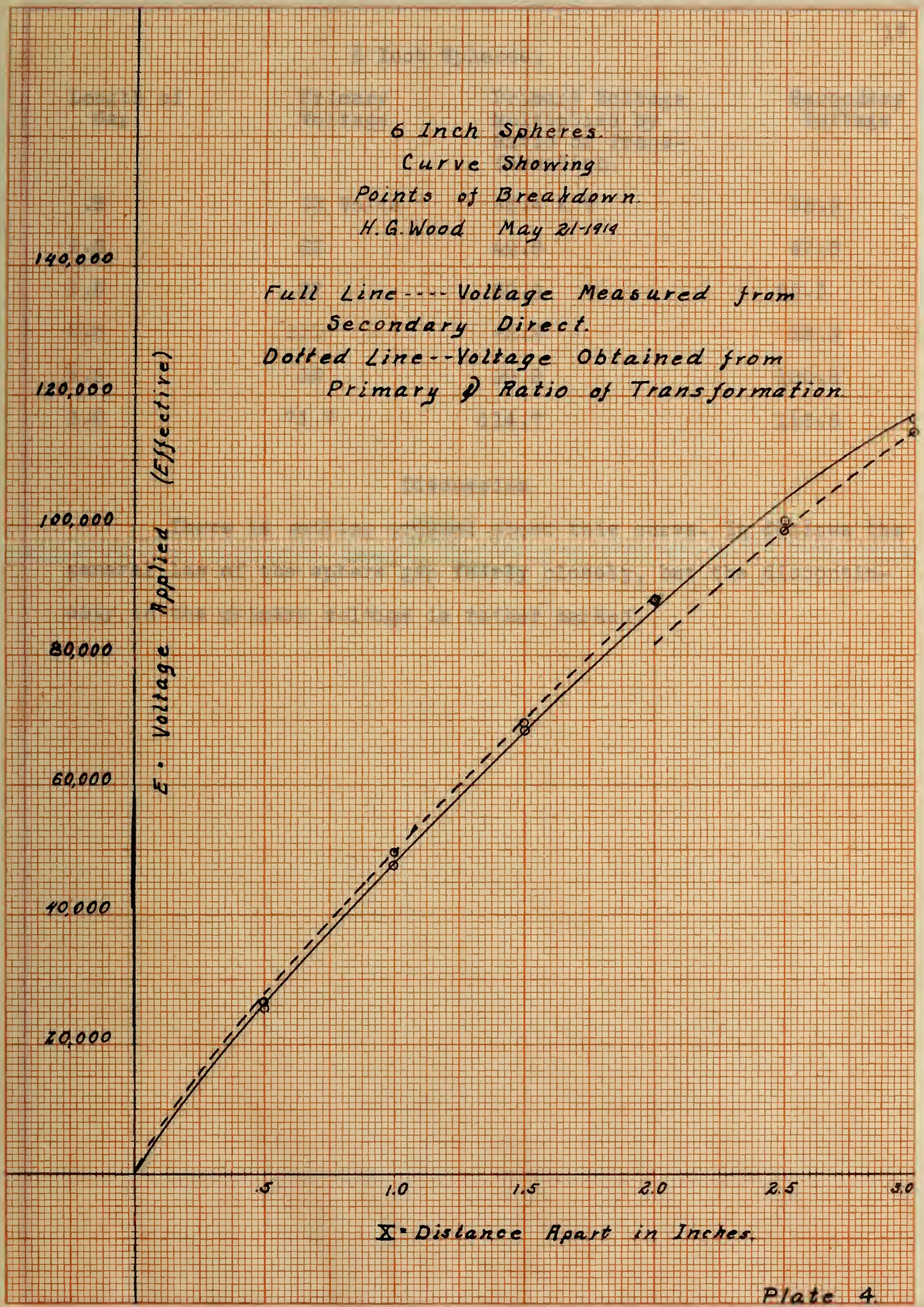


Plate 4.

NO 346
EUGENE DIETZGEN CO. CHICAGO NEW YORK

6 inch Spheres
Curve Showing
Points of Breakdown
H.E.Wood May 21-1914

Full line---Voltage Measured from
Secondary Direct
Dotted line--Voltage Obtained from
Primary & Ratio of Transformation

E. Voltage (Effective)

140,000
120,000
100,000
80,000
60,000
40,000
20,000

X- Distance Apart in Inches

Plate 4

6 Inch Spheres.

Length of Gap	Primary Voltage	Primary Voltage Multiplied by Ratio of Transformation.	Secondary Voltage
.5	33 Volts	26.4 K V	25.5
1.0	62	49.6	47.5
1.5	87	69.6	68.3
2.0	111	88.8	88.5
2.5	62	99.2	100.8
3.0	71.7	114.7	116.5

Discussion

There is nothing unusual about this curve. It follows the general law of the sphere gap fairly closely, but the discontinuity in the primary voltage is rather marked.

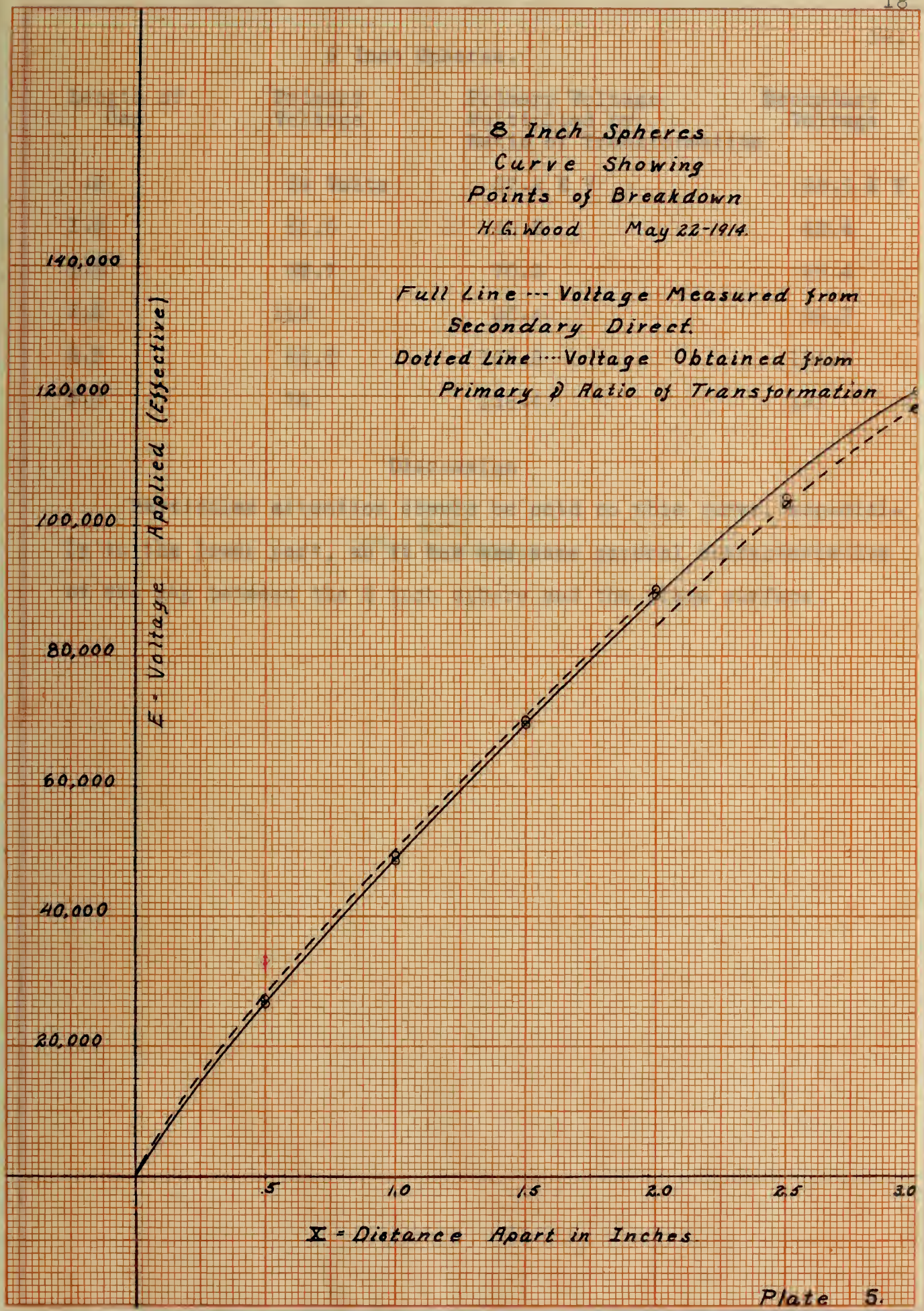


Plate 5.

NO 345
EUGENE DIETZGEN CO CHICAGO-NEW YORK

E - Voltage (Effective)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
5
10
15
20
25
30
X - Distance Apart in Inches

Plate 5

8 Inch Spheres.

Length of Gap	Primary Voltage	Primary Voltage Multiplied by Ratio of Transformation	Secondary Voltage
.5	34 Volts	27.2 K V	26.5 K V
1.0	61.5	49.2	48.4
1.5	87.7	70.2	69.4
2.0	113	90.4	89.3
2.5	64.5	103.2	104.5
3.0	74	118.4	121

Discussion

Particular attention should be paid to this curve, especially to the lower part, as it has the same general characteristics of the gap between the 8 inch sphere and the plane surface.

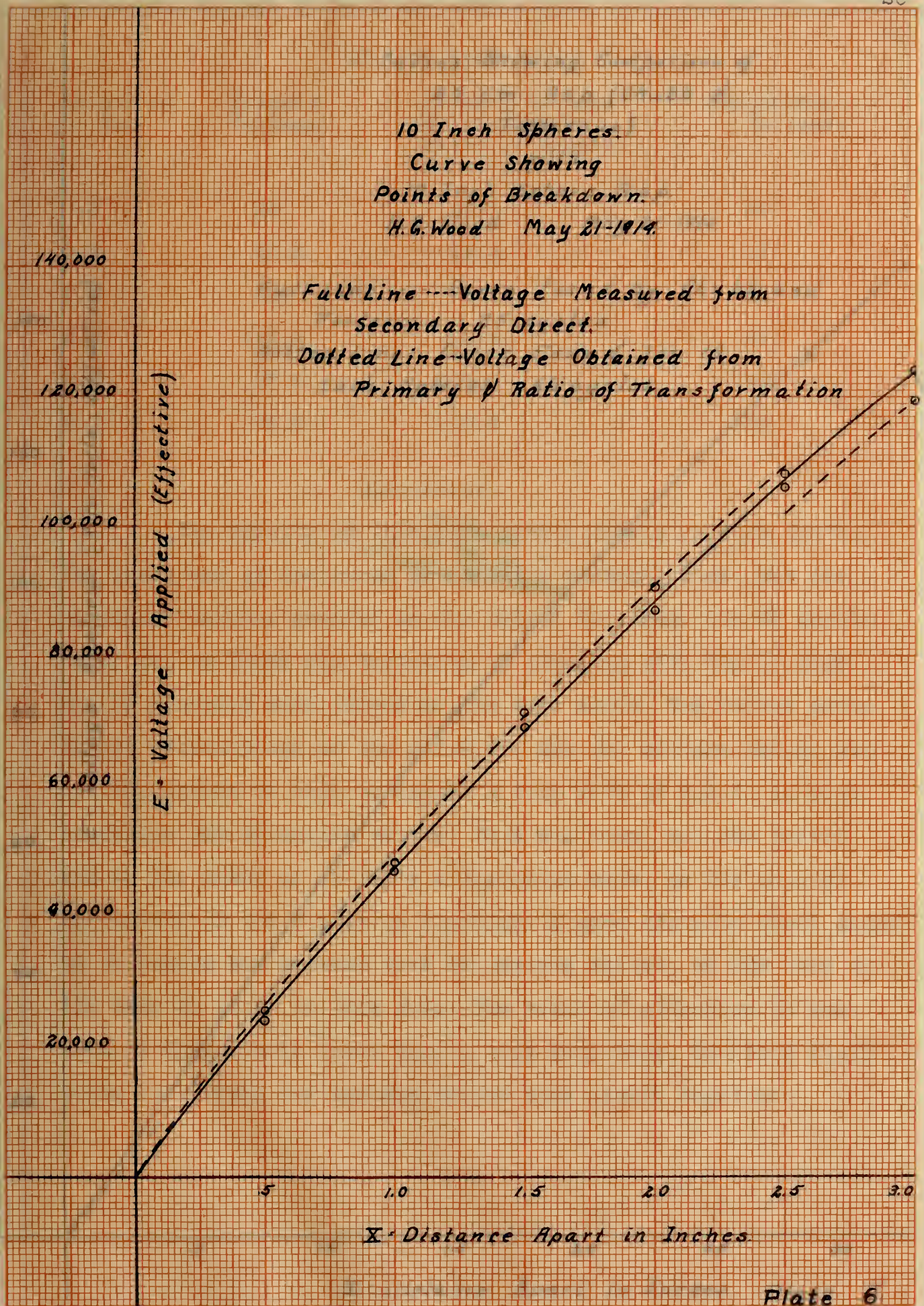


Plate 6

NO 346
EUGENE DIETZGEN CO. CHICAGO-NEW YORK

10 Inch Spheres
Curve Showing
Points of Breakdown
A.C. Wave May 21-1914

Full line --- Voltage Measured from
Secondary Direct
Dotted line-Voltage Obtained from
Primary & Ratio of Transformation

E - Voltage (Effective)

140,000
120,000
100,000
80,000
60,000
40,000
20,000

X - Distance Apart in Inches

Plate 6

Curves Showing Comparison of
25 Cm. Gap (Chubb & Fortescue)
with
10 Inch Sphere Gap.
H.G. Wood May 21-1914.

Full Line ---- Curve Found by Chubb and Fortescue - 25 cycles
Dotted Line -- Curve Found for 10 Inch Spheres - 60 cycles.

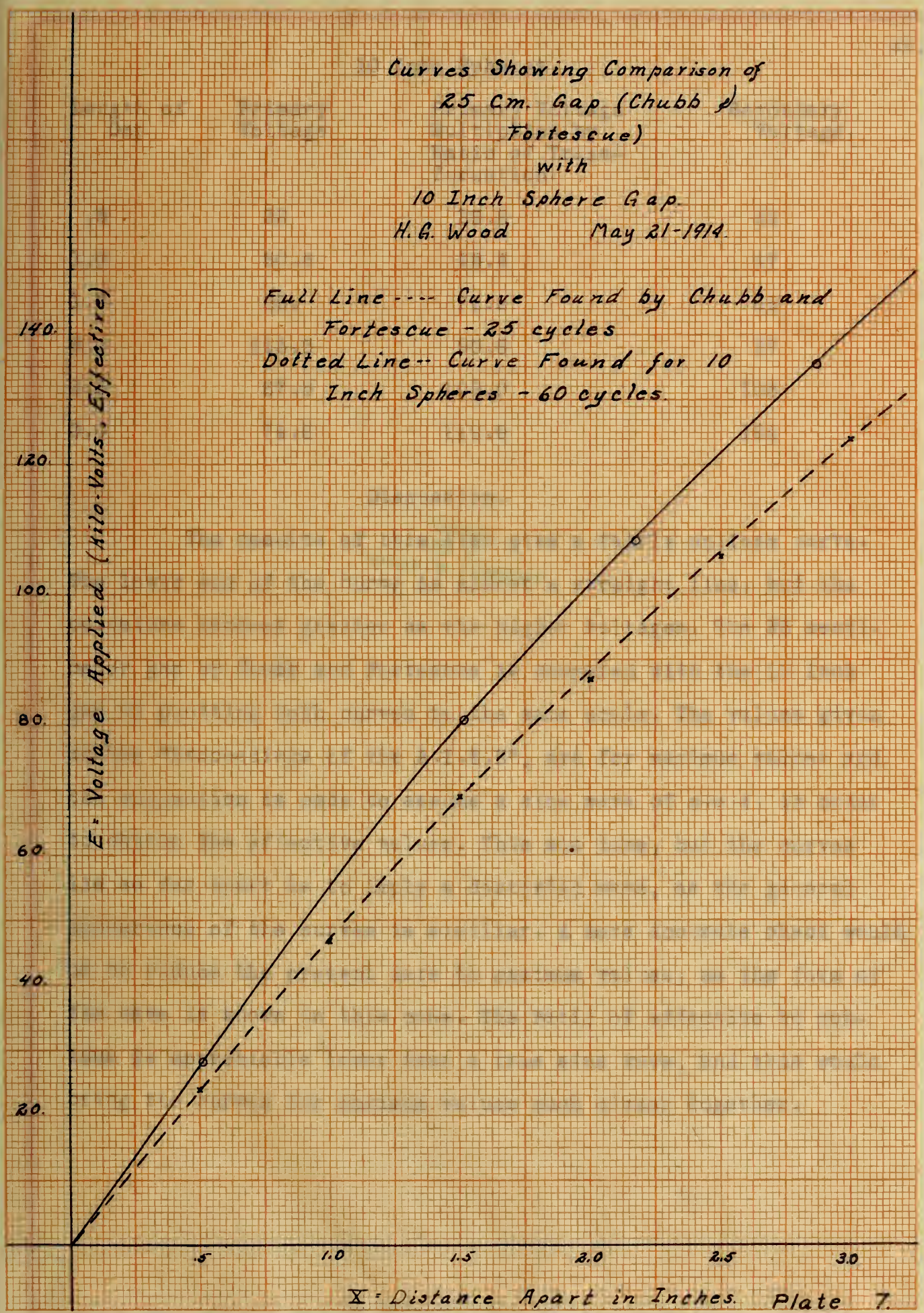


Plate 7.

NO. 346
EUGENE DIETZGEN CO. CHICAGO NEW YORK

Curves showing comparison of
25 Cm. Gap (Chubb &
Fortescue)
with
10 Inch Sphere Gap
M.I.T. Wood ... May 21-1914

Full line - Curve found by Chubb and Fortescue - 25 cycles
Dotted line - Curve found for 10 Inch Spheres - 60 cycles

E. Voltage Effective (Kilovolts)

120
100
80
60
40
20

K. Discharge Gaps in Inches Plate 7

10 Inch Spheres.

Length of Gap	Primary Voltage	Primary Voltage Multiplied by Ratio of Transformation.	Secondary Voltage.
.5	32	25.6	24
1.0	60.5	48.4	47
1.5	89.	71.2	69
2.0	113.5	90.8	87
2.5	67.5	108.0	106
3.0	74.6	119.9	124

Discussion.

The results of this list give a fairly uniform curve. The lower end of the curve is almost a straight line, but the curvature becomes greater as the higher voltages. The 25 centimeter gap by Chubb and Fortescue is compared with the 10 inch gap by plotting both curves to the same scale. The values given in the "Proceedings of the A.I.E.E", are for maximum values and the suggestion is made to assume a sine wave of e.m.f. in order to obtain the effective values. This was done, but the curves lie so far apart as to imply a distorted wave, as the general appearance of the curves is similiar. A more accurate check would be to reduce the present data to maximum values, as the form of the wave is known in this case. The ratio of effective to maximum is appreciable lower than a true sine wave, and this would bring the curves for maximum values much closer together.

Theory of Sphere-Plate Gap

The lines of electrostatic flux, in an ordinary sphere gap radiate from the two spheres on the elementary lines of an elipse, as shown below.

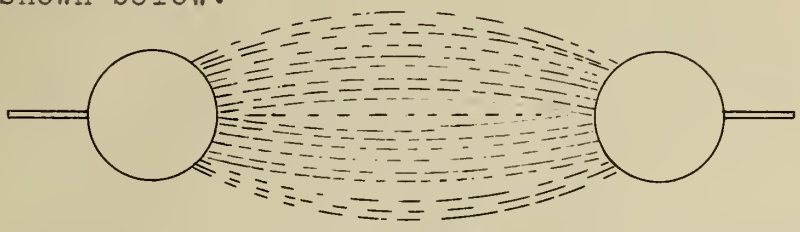
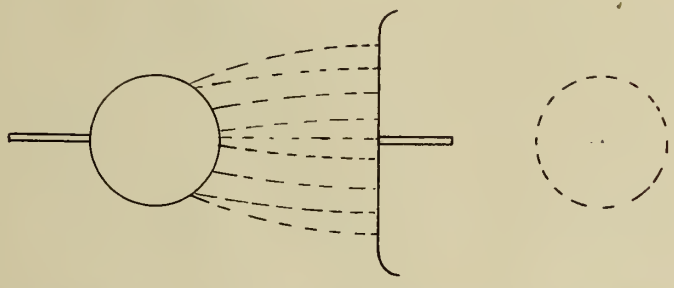


Fig. Vl.

If a flat surface of large size is introduced into the middle of this field, the linesof flux will pass into it normal to its surface. The second sphere may then be removed, and if the plate be connected to the same electrode and onehalf the original voltage be impressed, the field will have the same distribution as for the two spheres with twice the distance and twice the vol-voltage.



Fig, Vll.

This will only be absolutely true when the plane surface is infinite in extent, but for all ordinary tests, if the plate be three or four times as large as the diameter of the sphere, and the gap kept within reasonable size, very close results will be obtained.

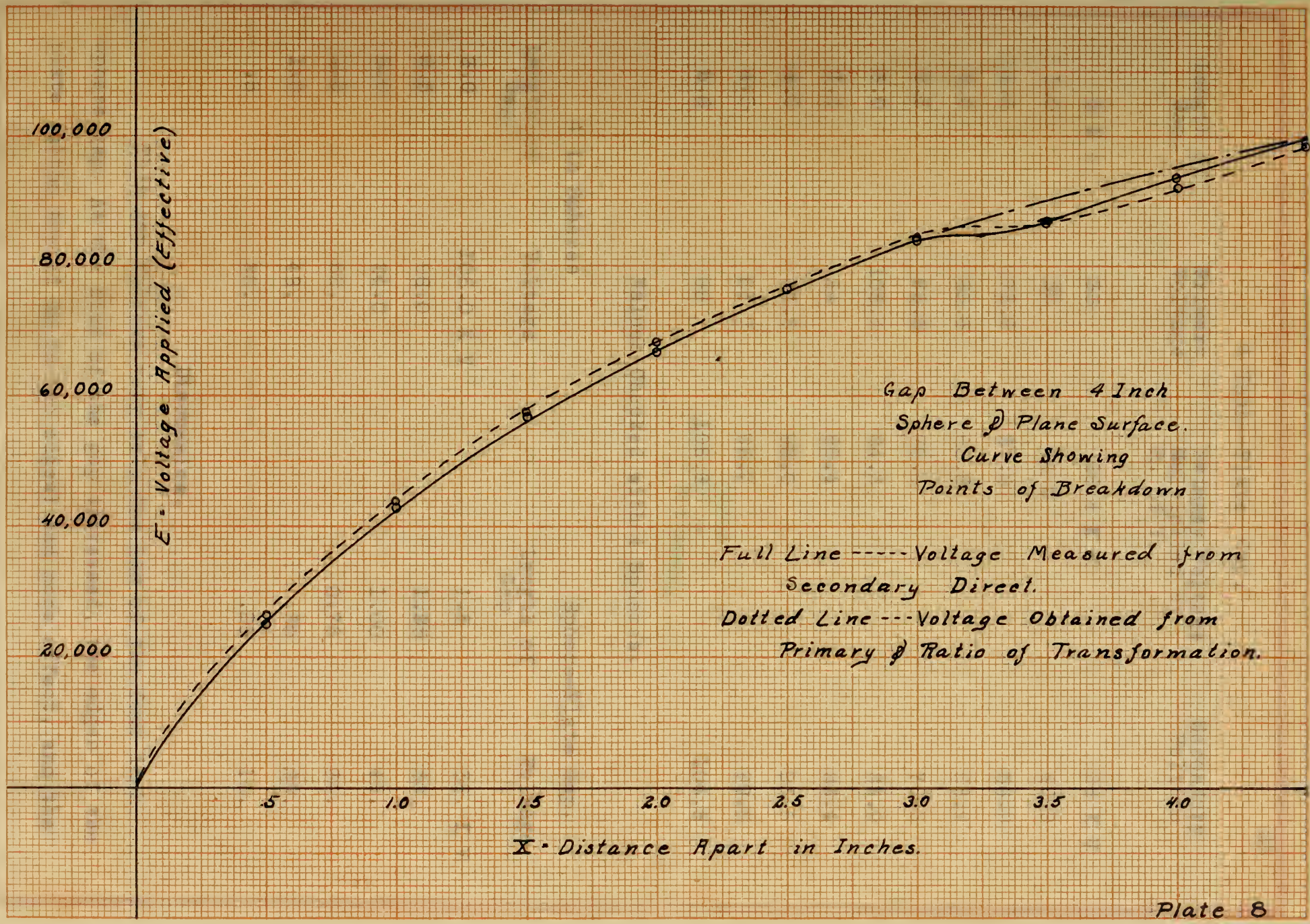

100,000
80,000
60,000
40,000
20,000
E - Voltage Applied (Effective)
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
X - Distance Apart in Inches.
Gap Between 4 Inch Sphere & Plane Surface.
Curve Showing
Points of Breakdown
Full Line ----- Voltage Measured from Secondary Direct.
Dotted Line --- Voltage Obtained from Primary & Ratio of Transformation.

Plate 8

Plate 8

Breakdown Voltage of Air between Plates

Curve is Plotted from Points Obtained by Measuring Breakdown Voltage with Decreasing Distance between Plates

Curve B Plotted from Points Obtained by Measuring Breakdown Voltage with Increasing Distance between Plates

4 Inch--Plate Gap.

Length of Gap.	Primary Voltage	Primary Voltage Multiplied by R. of T.	Secondary Voltage
.5 In.	33	26.4 K V	25 K V
1.0	55	44.0	42.9
1.5	72.2	57.8	56.9
2.0	85.3	68.2	66.9
2.5	95.5	76.4	76.3
3.0	105.4	84.3	83.9
3.5	54	86.4	86.4
4.0	57.5	92.0	93.6
4.5	61.7	98.7	99.5
5.0	66	105.6	104.5

Values Checked with 4 Spheres.

4 In Spheres

Length of Gap	Voltage
3.0	106.0 K V
2.5	96.0
2.0	84.0
1.5	68.
1.0	48.
.5	26.

Sphere-Plate Gap.

Length of Gap	Voltage
1.5	56. K V
1.25	50.
1.00	42.
0.75	34.
.50	25.
.25	14.

Discussion.

This gap follows very well the law of the four inch sphere gap. As the size of the gap increased, the edges of the plate (altho turned up on two edges) had more effect, and the

variation from half of the voltage obtained from the sphere gap is more marked. From the two inch gap down, however, the two curves follow each other very closely.

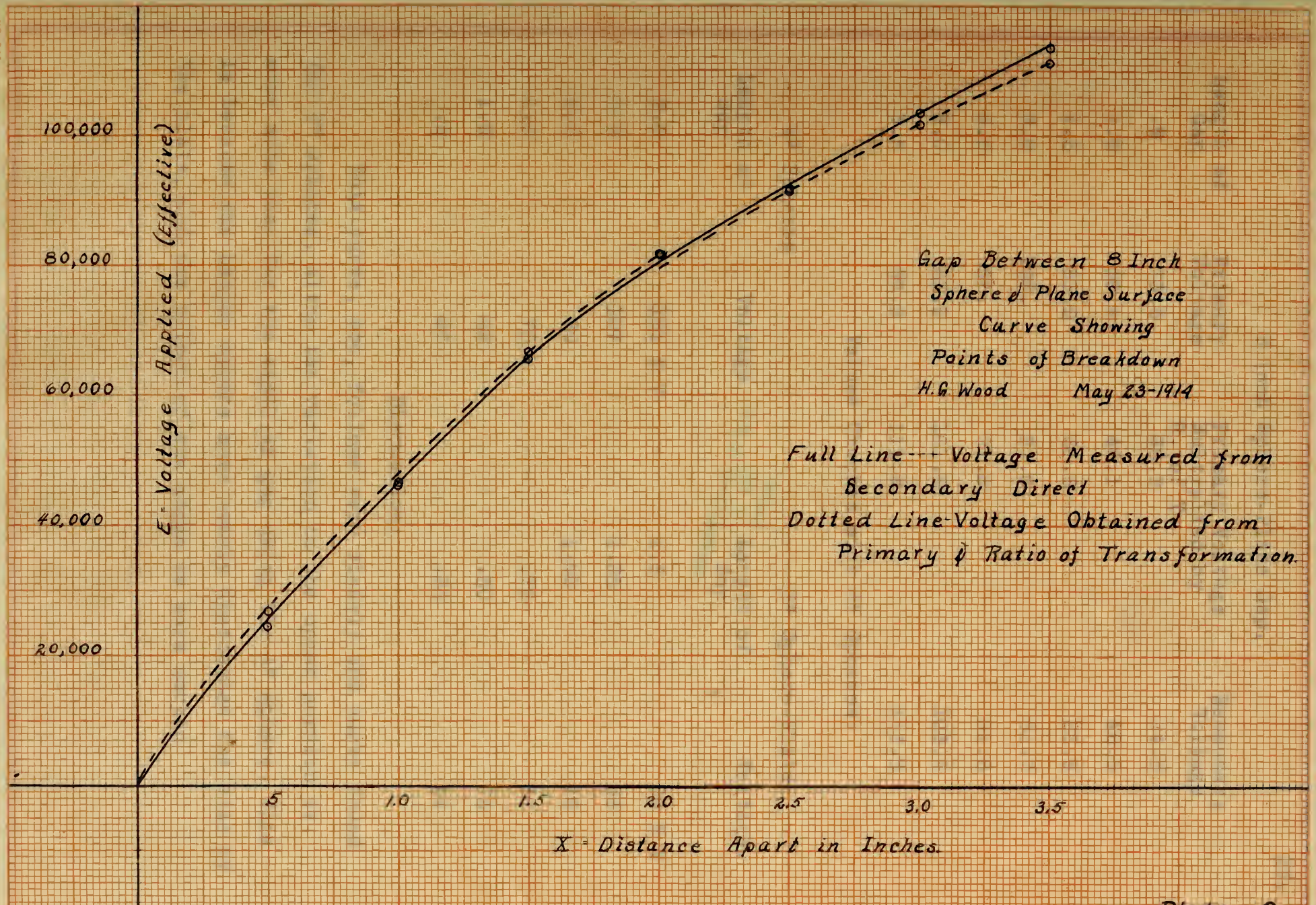

100,000
80,000
60,000
40,000
20,000
E = Voltage Applied (Effective)
.5
1.0
1.5
2.0
2.5
3.0
3.5
X = Distance Apart in Inches.
Gap Between 8 Inch Sphere & Plane Surface
Curve Showing
Points of Breakdown
H.G. Wood May 23-1914
Full Line --- Voltage Measured from Secondary Direct
Dotted Line-Voltage Obtained from Primary & Ratio of Transformation.

Plate 9.

Fig. 3.

Primary & Secondary Current Relation
Ratio of Transformation 1 : 10
Full Line : Actual Ratio
Dotted Line : Theoretical Ratio
Secondary Current in Amperes

Primary Current in Amperes

8 Inch Sphere-Plate Gap.

Length of Gap	Primary Voltage	Primary Voltage Multiplied by R. of T.	Secondary Voltage
.5	33.5	26.8	24.5
1.0	59.6	46.1	46.5
1.5	83.5	66.8	65.5
2.0	102.	81.6	81.7
2.5	57.	91.2	91.8
3.0	63.5	101.6	103.5
3.5	69.5	111.2	113.5

Values Checked with 8" Spheres.

8" Spheres		8" Sphere-Plate	
Length of Gap	Voltage	Length of Gap	Voltage.
3.0	121 K V	1.5	66 K V
2.5	107	1.25	56
2.0	89	1.00	46
1.5	70	.75	36
1.0	49	.50	25
.5	27	.25	14

Discussion.

This curve, too, follows very closely the curve found for 8" spheres, altho the variation in the upper portion is more wide than for the similiar gap using the 4" sphere. This is because the larger sphere more nearly approaches the size of the plate, and the effect of the edges is more marked

General Discussion and Conclusions.

The sphere gaps gave (with the possible exception of the two inch spheres) uniformly good results. In some cases the same spheres were used on different days, and the results checked very closely, within the range of readings taken, for the same point, in most cases.

The gaps were tried both with and without a fan. When the fan was not in use, a gradual drop in the voltage necessary for breakdown was noticed, due to the ionization of the air. When the fan was used, the readings were much more uniform, the whole series of readings being about equal to the voltage on the gap at which the first one or two discharges took place without the fan blowing. Thus it is seen that the use of the fan is beneficial, rather than otherwise, and also shows that the sphere gap volt meter is adapted to out door work.

The gap between a sphere and a plate, while not very adaptable for ordinary testing would give a convient method of investigating much higher potentials than would otherwise be possible, by studying the characteristics of the similar curve. The behavior of a given sphere gap could be predicted to a voltage double that avaible to the investigator.

It seems that the sphere gap may be used with confidence to obtain voltages where the accuracy desired does not preclude errors of less than one percent. With more careful measurement of gaps, correction for humidity, frequency, wave shape, etc., results even more accurate might be obtained.

The method of measuring by means of taps in H.T. windings appears to be one of the best thus far suggested, since there is little chance of error in voltage indications thus obtained.

The only serious objection to it seems to be the difficulty of safely bringing out the taps.

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